FECAL CONTAMINATION OF IRRIGATION WATER: KEEP IT OFF THE DINNER TABLE

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Contamination of fresh, ready-to-eat fruits and vegetables with pathogens is a significant issue for U.S. agriculture. In many cases, fecal-oral pathogens such as toxin-producing *E. coli*, *Salmonella spp.,* and norovirus are the causative agents (Heaton and Jones, 2008). Traceback analysis, to identify when contamination occurred in the production chain, can be a daunting task (Doyle and Erickson, 2008). Fecally contaminated irrigation water frequently is indicated as either a possible source, or as the likely source, that leads to contamination of fresh, ready-to-eat fruits and vegetables with pathogens (Liefert and others, 2008). According to the Centers for Disease Control and Prevention (CDC) (www.cfsan.fda.gov/~dms/prodpla2.html, accessed 02 December 2008), at least 12 percent of foodborne outbreaks in the 1990s were attributable to fresh produce, and the economic cost of foodborne illness is $10 to $83 billion per year.

Once pathogenic microorganisms contaminate fruits and vegetables, ambient conditions influence whether they die, persist, or grow. Key factors that affect pathogen survival on plant surfaces include microbe-microbe interactions (competition with native bacteria, collaboration with invasive fungi), plant-microbe interactions (both positive and negative), exposure to sunlight (germicidal ultraviolet irradiation), and desiccation (Heaton and Jones, 2008). Relatively few studies have investigated the effects of these phenomena (reviewed in Aruscavage and others, 2006; Steele and Odumeru, 2004). Representative survival statistics are summarized in Table 1.

Various produce sanitation practices (washing, disinfection, and other treatments) can reduce but not eliminate contaminating pathogens from plant surfaces. Stringent disinfection treatments can reduce pathogen loads by 99.9%, but many treatments are less effective (Aruscavage and others, 2006; Bassett and McClure, 2008). Depending on the level of contamination, health risk from residual pathogens may be unacceptable. Washing and disinfection practices are less effective against pathogens that succeed in penetrating the plant interior (Aruscavage and others, 2006). For these reasons, prevention of contamination is considered a primary means to control health risk from foodborne pathogens (Leifert and others, 2008).

"Food Safety Begins on the Farm: a Growers' Guide" lists the following sources of fecal-oral pathogens that contaminate produce (Rangarajan and others, 2003):
- Soil
- Irrigation water
- Animal manure (untreated manure, inadequately composted manure, or direct contamination by animals in the field)
- Field workers
- Equipment (harvesting and transport)

- Wash and rinse water
- Produce handlers (during packing, wholesale and retail operations, and at home)
- Ice, cooling units, contact with other contaminated products, and other cross-contamination vectors

Among these potential sources, the role of irrigation water is perhaps the least well understood. Traceback analysis after outbreaks, by definition, is a historical analysis that takes place weeks or months after crops were last irrigated. Because water conditions change rapidly, especially for surface water, assessment of water quality used for irrigation is extremely difficult—often impossible—so long after the irrigation event. Published reports only rarely give information about the sanitary quality of water used for irrigation, although a few that have done so are reports from Ontario, Canada (Steele and others, 2005), and Arizona (in Gerba and Choi, 2006). No information is available about the quality of irrigation water that was used for crops that ultimately led to outbreaks of foodborne illness. Lacking this information, informed decisions about acceptable quality of irrigation water are difficult to make.

Though no comprehensive survey of fecal contamination levels in irrigation water has yet been accomplished, information from the U.S. Geological Survey (USGS) National Water Information Network (NWIS; available online at http://waterdata.usgs.gov/nwis) can be useful when evaluating source-water quality. For example, the USGS analyzed nearly 3,500 surface-water samples from Ohio for *E. coli* density between April 1992 and September 2005. This sample set was not designed to be representative of irrigation-water quality, and it may be biased toward contaminated samples because specific sites were targeted for intensive monitoring. Nevertheless, the characteristics of these data have interesting implications with regard to irrigation-water quality. Overall, 35% of the samples contained fewer than 126 colony-forming units per 100 mL (CFU/100 mL), 13% contained between 126 and 235 CFU/100 mL, 20% contained between 235 and 576 CFU/100 mL, and 32% contained more than 576 CFU/100 mL *E. coli*. The breakpoints in this analysis represent criteria promulgated by U.S. Environmental Protection Agency for recreational water quality (USEPA 2004).

The USEPA recreational-water quality criteria have been put forth for potential incorporation into the Commodity Specific Food Safety Guidelines for the Production and Harvest of Lettuce and Leafy Greens (current version available at www.cfsan.fda.gov/~acrobat/lettsup.pdf) by the California Leafy Green Products Handler Marketing Agreement (www.caleafygreens.ca.gov). The June 2007 draft document recommends at least monthly sampling of irrigation water sources. Acceptance criteria for preharvest foliar application are similar to the criteria for designated swimming beaches (rolling geometric mean of 5 samples less than or equal to 126 CFU/100 mL and no single sample higher than 235 CFU/100 mL). For preharvest nonfoliar applications, the acceptance criterion for single measurements would be relaxed (rolling geometric mean of 5 samples less than or equal to 126 CFU/100 mL and no single sample higher than 576 CFU/100 mL). For postharvest applications such as equipment cleaning and product rehydration and cooling, the water-quality criterion would be similar to that for potable water (drinking water; that is, less than 1 CFU/100 mL *E. coli*).

Water-quality criteria promulgated by USEPA, such as the recreational-water quality criteria cited above, are based on a target risk level. Calculation of the recreational-water quality

criteria was based on the desire to meet a risk level of 8 cases of gastrointestinal illness per 1,000 swimmers per year (Dufour, 1984). The relation between *E. coli* density and gastrointestinal illness is complex and depends on many factors, including

- the relation between the indicator (*E. coli*) and the density of pathogens capable of causing gastrointestinal illness
- the amount of contaminated water ingested
- the susceptibility of the subject to disease
- the infectivity of the pathogen.

One would expect each of these factors to differ for water recreation and consumption of irrigated crops. Thus, it is exceedingly unlikely that the risk posed by swimming in water with a particular level of fecal contamination is equivalent to the risk posed by consuming produce that was irrigated with the same water source.

Gerba and Choi (2006) proposed a risk target of 1 illness in 10,000 persons per year, the same target used for drinking water in the United States. Microbial risk assessment models have been used to estimate the maximum density of specific pathogens in water corresponding to this risk level (Stine and others, 2005); however, extrapolation of these values to *E. coli-* or other indicator-based water quality criteria has, thus far, not been accomplished. Extensive evaluation of irrigation-water quality, both in terms of fecal-indicator bacteria density and occurrence of key pathogens, will be a necessary first step for eventual science-based criteria for irrigation-water quality. Until these criteria are developed, it remains difficult to judge the level of irrigation-ater quality necessary to keep produce contaminated with fecal-oral pathogens off of the dinner table.

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Table 1: Survival of pathogens on contaminated fruits and vegetables

Location	Pathogens	Survival statistic	Notes	Citation
Carrot and radish roots, grown in irrigated soil	*Salmonella typhimurium*	Initial 5-log decline (28 days), followed by persistence in soil to >180 days.	Detected on field-grown radishes >80 days and carrots >180 days after irrigation.	Islam and others, 2004
Lettuce, overhead irrigated	*E. coli* O157:H7	Detected on edible leaves >20 days after irrigation.	Plant growth conditions not fully described (exposure to solar irradiation, rainfall, desiccation).	Solomon and others, 2003
Various (review article)	*E. coli* O157:H7 and *Salmonella spp*.	Persistence ranging from 20 to 161 days on plant surfaces (leaf and tomato).	Information included in Table 1 of citation, summary of 12 references.	Aruscavage and others, 2006
Various (review article)	Summary of many bacterial and viral pathogens	Bacteria generally survive fewer than 15 days. Enteroviruses generally survive fewer than 15 days.	Summarized from prior reports, many of them obscure.	Steele and Odumeru, 2004